A SIMPLE ELECTRODYNAMIC MODEL OF A DUST DEVIL.

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Introduction: There exists a widely known dust dust whirl, which is an almost vertical cloud of dust – see Fig. 1[1].We present an electrodynamic model of a dust devil applying a similar methodology as performed previously for charging in terrestrial thunderstorms.

Fig.1

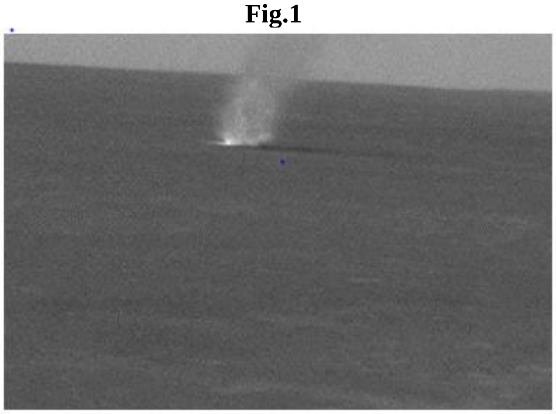

Fig.2

such dust whirls are also moving on Mars, where there is no atmosphere - see. Fig. 2. While thunderstorm processes focus on inductive charging between large graupel and smaller ice and water droplets, we tailor the model to focus on the electric charge transfer between dust grains of different sizes and compositions. We specifically compare and contrast the triboelectric dust charging processes presented previously in William M. Farrell 24 October 2003. Dust devils form via fluid micro-instability associated with the inversion of a surface-warmed air mass and cooler overlying layers.[3] Pressure gradients develop in these systems, which force dust grains upward, and in the process act to form coherent convective miniature cyclones. Such dust formations are generated at the airsurface interfaces both on Earth and on Mars.[4] In dust devils, grains in contact with each other and the surface are known to generate and transfer electric charge via frictional or triboelectric processes. This mass-based charging preference combined with the mass stratification within the convective devil leads to a macroscopic, vertically-stratified charge distribution in the devil and consequently the development of a large interdevil electrostatic potential. Large devil electric fields have been measured at kilovolt per meter strengths in the vicinity and within terrestrial dust devils and the charge separation and potential development process has been simulated in [2]. On Earth, dust devils tend to have heights of a few hundred meters and widths on the order of tens of meters. These ‘‘minitornados’’ consist of cyclon istrophic winds (where centripetal forces balance pressure gradient) on the order of 10–30 ms^{-1} , have warm cores with center temperature increases as high as 4C relative to ambient temperature, and central pressure decreases on the order of a few millibars below ambient pressure. The vertical winds created by the upward directed hot fluid elements in the central region tend to lift particle grains of various sizes. These winds also act as a mass stratification mechanism, with smaller, lighter grains tending to be lofted higher than the larger, heavier grains. The formation of dust devils is associated with an intrinsic atmospheric instability.. The instability manifests itself as convective plumes and vortices (when a source of vorticity is present). The dust devil is a visible manifestation of a vortex that has lifted dust and sand directly off of the surface. In these vortices, warmer air from the ground travels upward in the central region, and cooler air is pulled downward both within the core and in regions surrounding the vortex. Dust entrained in the upward moving fluid elements gives rise to the opaque central region.

Electrostatic Model :

In order to couple electrical and fluid models, we start with the electrostatic formalism that leaves a dependency of electric field on differential grain velocity. This grain velocity is then solved via fluid formalism to derive E as a function of the driving vertical winds. The electric field will be derived on the basis of the flow of vertical currents [6], with the upward flow of negative smaller grains representing one current source and the flow of positive larger grains representing another current source. The concept is parallel to the development of electrostatic fields in thunderstorms based on one-dimensional (vertical) current flow from upward positive light ice and downward negative graupel and raindrops [7]. For this work, the derivation will initially parallel that of [6], but will deviate when considering the relative velocity of the grains. The development of the dust devil electric field, E, can be obtained from the continuity equation as,

$$de/dt = -J/\varepsilon o \quad (1)$$

where the current density is

$$J = n_L Q_L v_L + n_S Q_S v_S + \sigma E \quad (2)$$

with nL,S are the number density of the large and small particles, respectively, QL,S are the charge on the large and small particles, respectively, vL,S are the vertical velocities of the large and small particles, respectively, s is the local atmospheric conductivity and ε0 is the free space permittivity. The sE term represents the current dissipation into the atmosphere. An illustration of these currents . While we anticipate the development of charge centers within the devil, we also expect that the overall charge in the devil to have a net value of zero, making $n_L Q_L = -n_S Q_S$ and

$$J = n_L Q_L \Delta V + \sigma E \quad (3)$$

Where $\Delta V = v_L - v_S < 0$ is the differential velocity between large and small grains. A similar assumption is applied in thunderstorm charging [7] While charge neutrality is applied and the system is treated as closed, in reality some charge may escape, and a discussion of the relaxing of charge neutrality is presented in the conclusions We now place equation (3) back into equation (1) and time differentiate, now assuming Dv/ Dv(t), and not uniform in time as was performed previously The differential equation governing the temporal evolution of the electric field is then

$$E^{//} + \sigma E^{/} / \varepsilon o = -n_L (Q_L^{/} \Delta V + Q_L \Delta V^{/})/\varepsilon o \quad (4)$$

where the ‘‘/’’ indicates the time differentiation operation, d/dt. The time rate of change of charge on the large grain is QL / = nDq where n is the grain-grain collision frequency and Dq is the charge exchange in each collision. The collision frequency between large and small grains is n = prL 2 Dv nS and Dq have been estimated for grains of similar composition and varying composition and a contrast of the two models has been presented by Farrell et al. [2003]. We shall assume that charge exchange is for large and small grains of differing compositions making where rf is the reduced radius, In the calculations, we assume that the triboelectric potential between larger grains and smaller grains is 2V (i.e., large grains are insulators, while small grains are metallic, making small grains charge negative on collisions [8].The differential equation (4) has two driving terms associated with the development of two different currents: The first current, QL / Dv, is associated with changing grain charge moving at constant differential velocities, and the second current QLDv/ is associated with charged grains undergoing differential acceleration. [6] assumed that the differential velocities were constant at all times, and hence only included the first term in their model. However, we now relax the constant differential velocity assumption, and find that the second current term appears in the derivation for Dv = Dv(t). This QLDv/ term is important in the early part of dust devil formation. As we demonstrate in the next section, Dv varies with time in a complicated way during the early period of dust lifting and this second current term now couples this acceleration into the electric field formalism.In the most general sense, the importance of the Dv cannot be understated: This differential particle velocity is dependent upon the lifting process associated with the fluid, and via equation (4) links the electrostatic formalism to the fluid properties of the medium, particularly wind speed, V. We now directly connect E to wind speed V. We shall discuss the results during the conference.

References:

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